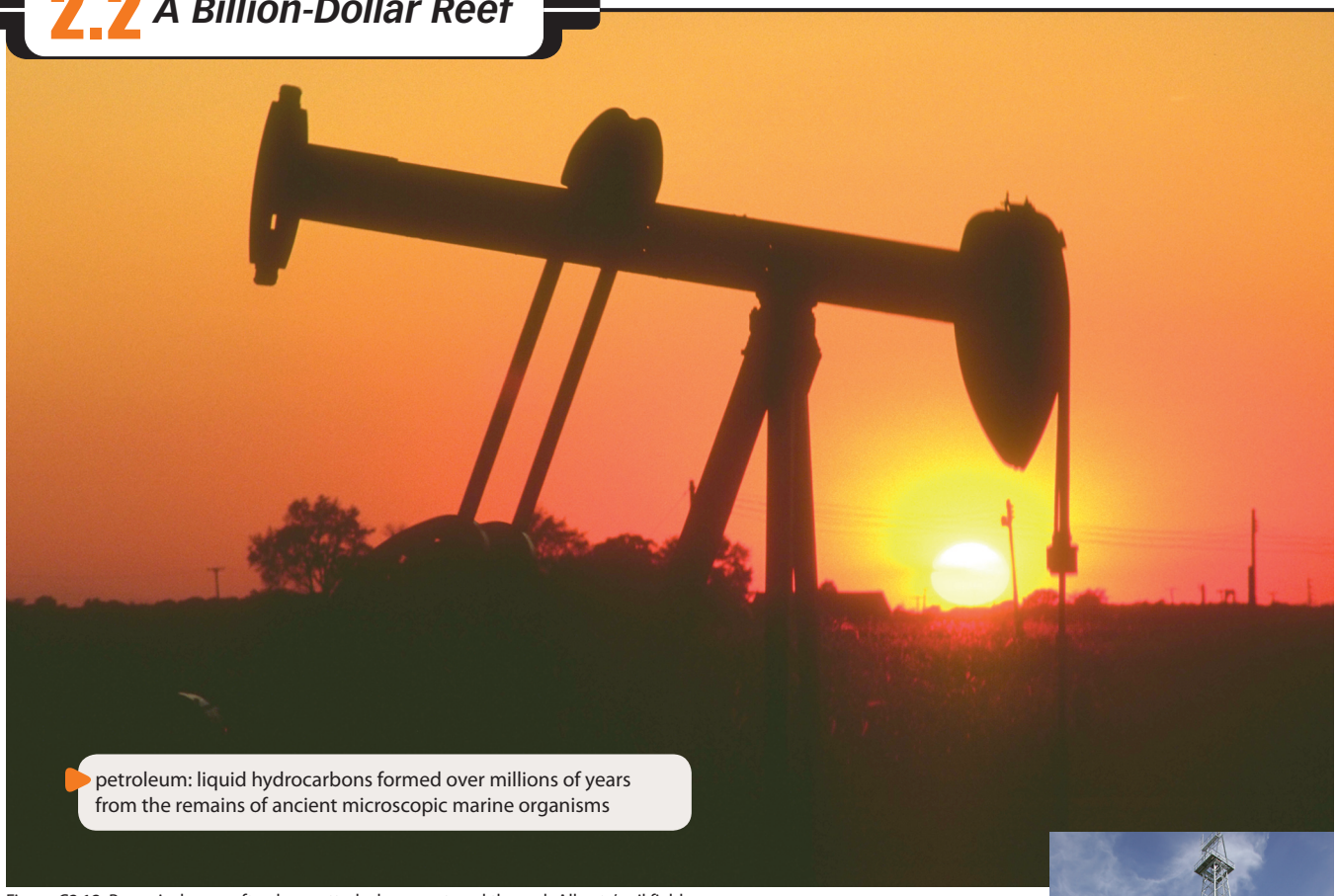
2.2 A Billion-Dollar Reef



petroleum: liquid hydrocarbons formed over millions of years from the remains of ancient microscopic marine organisms

Figure C2.12: Pump jacks can often be spotted when you travel through Alberta's oil fields.

Figure C2.13: The Leduc #1 oil well was built in 1947.

As you drive around Alberta you can't help noticing the landscape of mountains, trees, grasslands, and oil wells. You may pass, or be passed by, a number of trucks owned by various oilfield service companies. Just south of Devon, you will find the Leduc #1 Provincial Historic Site.

The Leduc oil field has produced more than 400 million barrels of **petroleum** since its discovery in 1947. This discovery came after more than 130 dry holes were drilled. Dry holes are wells that don't produce profitable amounts of petroleum or gas. Clearly, this is an example of persistence paying off because the discovery of petroleum associated with Leduc #1 radically changed Alberta from a farm-based economy to one based upon petroleum. Alberta's prosperity and its status as Canada's top energy-producing province are due to its rich reserves of petroleum.

Wealth from Ancient Seas

It's natural to wonder about the source of Alberta's good fortune. How was the petroleum formed? Why are these vast reserves found under Alberta and not beneath other provinces? The answers to these questions can be found in the clues about Alberta's ancient past left in the fossil record.

Earlier in this chapter you saw how the Burgess Shale preserved a fantastic record of life in the Cambrian Period of the Paleozoic Era. During this period, life on Earth was aquatic. The Cambrian Period was followed by the Ordovician Period, which was marked by life moving from water to the land. The earliest fossils of terrestrial plants date back 470 million years. The Ordovician Period also saw the emergence of jawless fishes thought to be the first animals with backbones. Geologists suspect most of Alberta became submerged at the bottom of a tropical sea by the end of the Ordovician Period. Over the next 200 million years, sea levels rose and fell in a complicated pattern that is a challenge to reconstruct. When it was submerged, Alberta became the home to a now extinct group of sponges. These sponges secreted a brittle calcium carbonate skeleton that, together with coral, became the main component of huge reefs that eventually occupied hundreds of square kilometres of the underwater environment.

470 million years ago: first terrestrial plants

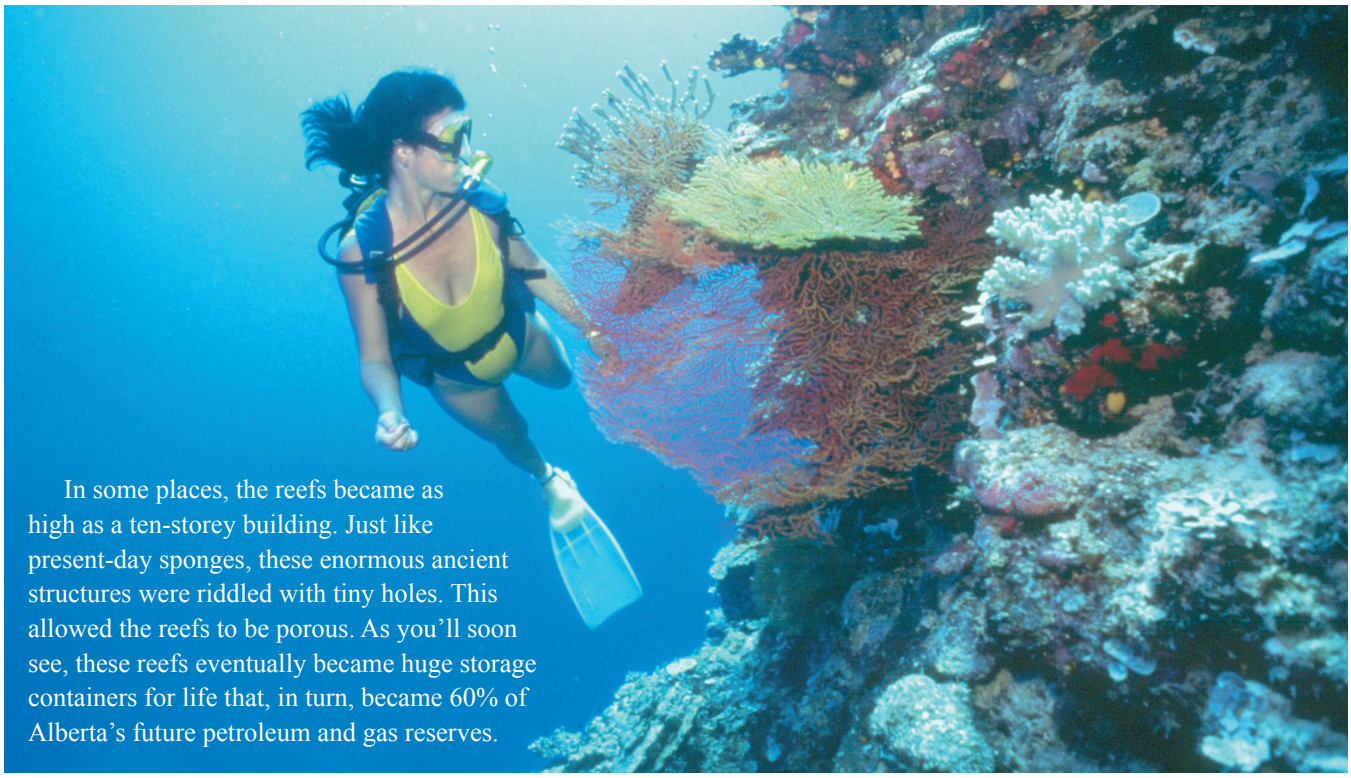

In some places, the reefs became as high as a ten-storey building. Just like present-day sponges, these enormous ancient structures were riddled with tiny holes. This allowed the reefs to be porous. As you'll soon see, these reefs eventually became huge storage containers for life that, in turn, became 60% of Alberta's future petroleum and gas reserves.

Figure C2.14: Alberta was once the home of many reefs.

Practice

11. Refer to the "Geological Time Scale" on page 312. Determine the length of the time interval represented by the Ordovician Period.
12. During the Ordovician Period, it is thought that land plants began to contribute to the levels of atmospheric oxygen. You will need to recall key ideas from previous science courses to answer the parts of this question.
    a. Describe the process by which plants produce oxygen as a by-product. Include a chemical equation to aid your description.
    b. Some geologists believe it is not accidental that evidence from the fossil record suggests the first amphibians appeared on land 40 million years after the appearance of the first land plants. It has been suggested that this time period was necessary to provide enough oxygen to help produce an atmospheric ozone layer. Explain why an atmospheric ozone layer would be important to early amphibians.

Making Petroleum

The Ordovician Period was followed by the Silurian Period. During this time, sponges continued to expand their hold on Alberta's watery landscape and reefs continued to grow. For the parts of Earth not underwater, the colonization of the land by primitive plants was nearly complete. The first land-dwelling animals—scorpions and millipedes—began to leave their traces in the fossil record.

500 to 300 million years ago:
accumulation of organic matter
to be transformed into petroleum

Then came the Devonian Period, when reef building reached its apex. Since the Ordovician Period, microscopic marine organisms—mostly plankton—had been living and dying in the warm tropical seas that often covered most of Alberta for tens of millions of years. Many geologists suspect that the dead plankton remains created thick blankets of organic ooze that fell to the bottom of the sea to become a food source for bacteria. The bacteria were thought to have removed most of the oxygen and nitrogen from this organic matter to leave mostly carbon and hydrogen, which are the main ingredients of petroleum.

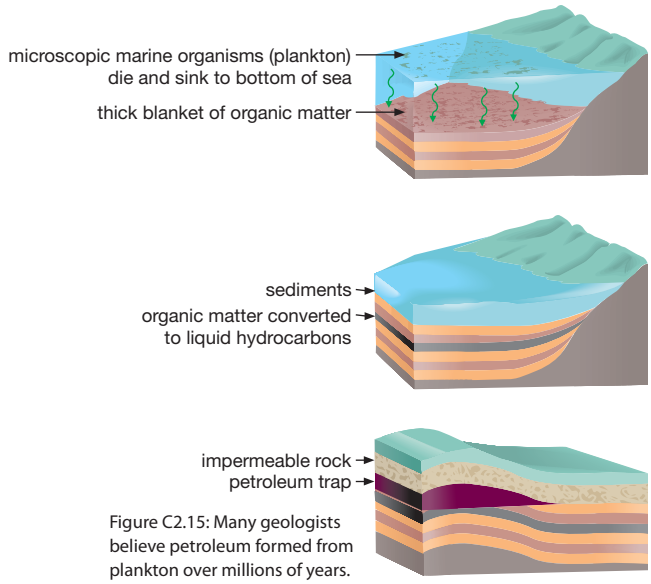

microscopic marine organisms (plankton) die and sink to bottom of sea
thick blanket of organic matter
sediments
organic matter converted to liquid hydrocarbons
impermeable rock
petroleum trap

Figure C2.15: Many geologists believe petroleum formed from plankton over millions of years.

During the next 380 million years, this layer of organic material was subjected to heat and pressure that encouraged chemical reactions to occur as thousands of metres of sediment were piled on top. The accumulated top layer of sediment eventually changed into rock. Once the hydrocarbons had been converted into liquids, the pressure from above pushed these materials into more porous rock—the fossilized remnants of the ancient reefs. Since the type of rock formed above and below the reservoir of petroleum was impermeable shale, the petroleum had no place to go. As with the Burgess Shale, when fine particles of mud and sediment are subjected to geological processes, the result is impermeable rock. This is why a large concentration of petroleum in subsurface rock is called a **petroleum trap**.

petroleum trap: a large quantity of petroleum confined between layers of impermeable rock

Practice

13. During the 140 million years from the beginning of the Ordovician Period to the end of the Devonian Period, Alberta was mostly submerged below a warm tropical sea. Explain the significance of this time period to the creation of Alberta's petroleum reserves.
14. Characteristics of ocean waters off the coast of the Bahamas are thought to be similar in many ways to tropical waters that once covered Alberta. Explain why petroleum cannot be extracted from the bottom of the shallow waters that surround the Bahamas.

When geologists first began to look for petroleum, they looked for evidence at Earth's surface. This usually meant finding places where petroleum had seeped to the surface. Finding this kind of evidence wasn't easy in Alberta because, other than in the foothills and mountains, there are very few outcrops of rock that would indicate petroleum reserves.

As you can see in Figure C2.16, the Devonian rock containing the petroleum traps was located 1 km below the surface.

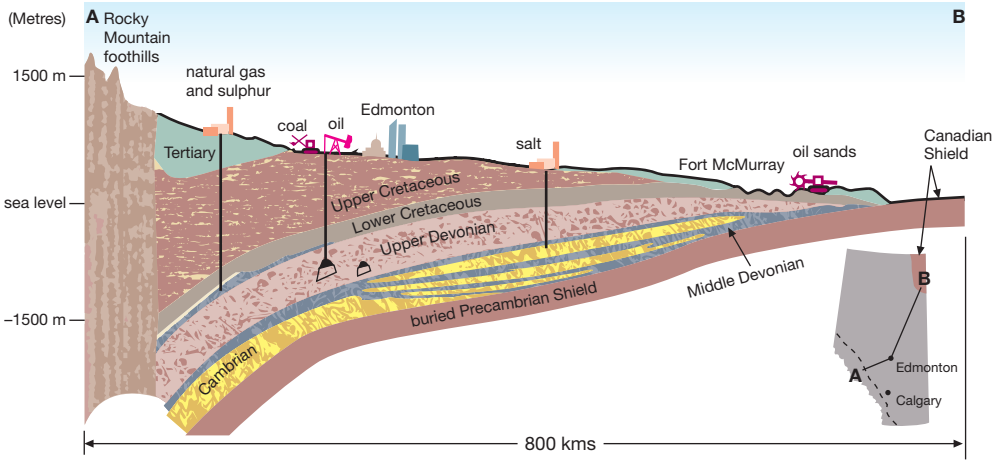


Figure C2.16: A cross section of Alberta shows major rock layers and some of the mineral resources they contain.

You can see the location of the Leduc oil field in Figure C2.16. It's located near Edmonton. How did geologists locate the petroleum trap that made Leduc #1 so famous in 1947? One method used was to drill a well and carefully examine the **drill-core** samples taken.

drill core: a cylindrical sample of subsurface rock taken during drilling operations and returned to the surface for analysis

The analysis of a drill-core sample allows geologists to identify the type of rock below the surface. Fossils may be present in the core sample. These fossils not only provide information about the age of the rocks, but they also reveal the environmental conditions. This information tells geologists if they are drilling into a reef or into rocks that formed in the deep water away from a reef.

After many years of drilling and studying thousands of drill-core samples, there is now a detailed picture of the subsurface rock under Alberta, as summarized in Figure C2.16.

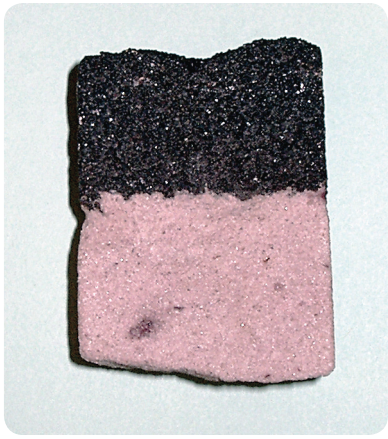


Figure C2.17: This section of a core sample is from a sandstone formation. The black material is crude oil.

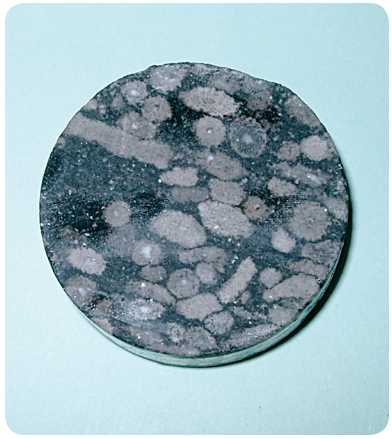


Figure C2.18: This top view of a limestone core sample shows fossil corals.

Investigation

Charting Patterns in Drill-Core Samples

Introduction

Imagine you are the newest geologist with Big Moose Petroleum. One of your jobs is to look at records from drill-core samples and draw cross sections of the rocks (similar to the one in Figure C2.16).

Science Skills

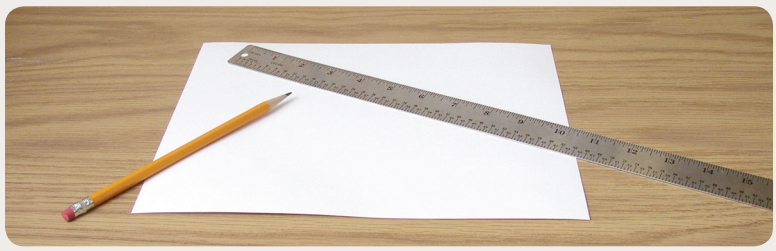
- ✓ Performing and Recording
- ✓ Analyzing and Interpreting

Purpose

You will use drill-core data to chart patterns in subsurface rock formations.

Materials

- blank piece of paper
- ruler
- pencil



Procedure

step 1: Prepare your piece of paper by recording a scale of 1 cm = 1000 m and a sign convention of left being west and right being east. Draw a horizontal line 14 cm long in the middle of your paper to represent the 14 km east/west line separating the first drill site from the last site.

step 2: Add the following information to the horizontal line on your diagram. Well 1 is located at the western (far left) end of the line, while well 2 is 5400 m east of well 1. Well 3 is 1400 m east of well 2. Well 4 is 2400 m east of well 3, and well 5 is the farthest east at 4800 m east of well 4. Add a label for the location of each well.

step 3: Refer to the "Drill-Core Data" table on the next page. In this step you will begin to plot the drill-core data under each well. Use a ruler to mark a tick at the boundaries between the rock layers under each well.

step 4: When all the boundaries (or contacts in geological terms) have been plotted, connect the tick marks with a smooth line or curve.

step 5: Transfer the labels from the "Drill-Core Data" table to your diagram of the rock layers under the wells.

DRILL-CORE DATA

Rock Type	Well 1 Depth (m) Comments	Well 2 Depth (m) Comments	Well 3 Depth (m) Comments	Well 4 Depth (m) Comments	Well 5 Depth (m) Comments
sandstone, shale, and thin coal	0 to 1000	0 to 1000	0 to 1100	0 to 1000	0 to 950
sandstone	1000 to 1550 shallow-water fossils	1000 to 1600 shallow-water fossils	1100 to 1600 shallow-water fossils	1000 to 1600 shallow-water fossils	950 to 1450 shallow-water fossils
shale	1550 to 2900 deep-water fossils	1600 to 2700 deep-water fossils—same age as fossils in well #1	1600 to 2000 deep-water fossils—same age as fossils in wells #1 and #2	1600 to 2800 deep-water fossils—same age as fossils in wells #1, #2, and #3	1450 to 2950 deep-water fossils—same age as fossils in wells #1 through #4
reef	not found	2700 to 3000 fossilized remains of sponges	2000 to 3000 fossilized remains of sponges—very old fossils at bottom of section	2800 to 3000 fossilized remains of sponges	not found
limestone	2900 to ? no fossils	3000 to ? no fossils	3000 to ? very few fossils	3000 to ? no fossils	2900 to ? no fossils

Analysis

The rock layers in your diagram have all been formed by geological processes that lasted millions of years. Sandstone is made from layers of sand particles compressed together. Shale is formed from compacting smaller particles of fine mud and silt. Limestone results from the compaction of carbonate minerals, usually precipitated out of seawater or formed of calcium carbonate from the shells of ancient sea life. Coal is formed from the compressed remains of land plants.

1. a. Identify each of the rock layers as sedimentary, igneous, or metamorphic.
   b. Label the oldest and the youngest layers of rock on your diagram. What principle are you using?
   c. Concisely describe how the region's environment between these wells changed over geological time.
2. Identify the most likely location of a petroleum trap on your diagram.
3. Even though the petroleum might be confined to a fairly large trap, it's not necessary to drill hundreds of wells into the same trap to extract most of the recoverable petroleum. Explain why it may take only one well to begin the process of extracting the petroleum from a large trap.

Seismic Waves

Figure C2.19: Leduc #1 was discovered in 1947.

The location for Leduc #1 was chosen on the basis of seismic information. Seismology is the study of how waves of energy—called **seismic waves**—move through Earth. Geologists have known for some time that natural events, like earthquakes, create seismic waves. But waiting for an earthquake to send seismic waves through the rock you want to study is inconvenient when searching for oil.

seismic waves: waves that travel through Earth as a result of explosions or earthquakes

Instead, geologists and geophysicists use two methods to generate the waves. One method is to use explosives placed in a hole. Another uses a system to vibrate a massive plate attached to a truck. The vibrating plate can strike the ground with a force of more than 3.1×10^5 N. The seismic waves travel through the ground, and some of the energy in the waves reflects off each boundary between the rock layers.

Recording the Data

Geophones on the surface detect seismic waves and convert them into electronic signals to be recorded. This is done in the same way microphones convert sound into signals. The data is then processed by a **seismograph**. Once the seismograph has analyzed the data, it can provide a summary of the results in the form of a **seismogram**. In Figure C2.20 you can see that the horizontal lines correspond to the horizontal layers of rock and the tilted lines correspond to the tilted layers of rock. Some boundaries reflect more energy than others, so they appear to be darker on the seismogram. Seismic exploration data can suggest where traps might be located, but only by drilling a well can you be sure if there is oil or gas present within the traps. In "Seismograph Simulation" you will have an opportunity to see the basic operation of a seismograph.

- seismograph: an instrument that records seismic waves
- seismogram: a record of seismic waves provided by a seismograph

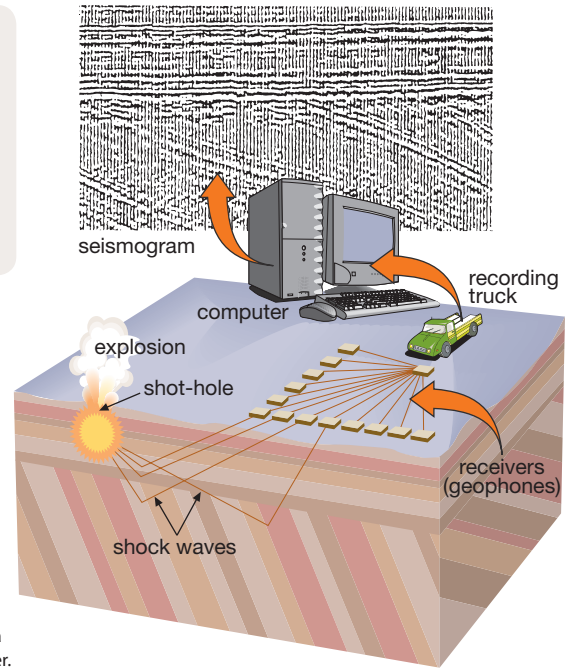


Figure C2.20: Explosives generate waves that travel through the rock. The waves reflect off the boundaries with other rock layers and return to the surface. Geophones convert the seismic waves into electrical signals to be processed by a specialized computer.

Utilizing Technology

Seismograph Simulation

Science Skills

✓ Performing and Recording

Purpose

You will observe a simulation of a seismograph in operation.

Procedure

Follow the instructions provided in the applet titled "Seismograph" on the Science 20 Textbook CD. Then answer the following questions.

Analysis

1. Would geophones first detect reflections in layers close to the surface or in deeper layers? Explain your answer.
2. Seismic exploration on land requires that geophones be arranged in lines, as in Figure C2.20. In forested areas, this requires that small roads and tracks be made in the forests, often for many kilometres. Briefly describe the environmental impact of these seismic lines. You will examine the environmental impact of seismic exploration in greater detail in Unit D.

2.2 Summary

Alberta remained near the equator following the end of the Cambrian Period and throughout most of the Paleozoic Era. During most of the Ordovician, Silurian, and Devonian Periods, Alberta was submerged under the shallow waters of warm tropical seas. The fossil evidence suggests that huge reefs flourished in these waters. Geologists think that microscopic marine life had been living in these tropical seas for tens of millions of years. The dead remains of these organisms created a thick blanket of ooze on the bottom of these seas that was eventually to become Alberta's reserves of petroleum. Most of Alberta's petroleum is found in the remains of ancient reefs.

Locating sources of petroleum in subsurface rock can be done by analyzing drill-core samples and by using seismograms. This information can help predict the location of petroleum traps.

2.2 Questions

Knowledge

1. Define the following key terms.

- **a.** petroleum
- **b.** reef
- **c.** petroleum trap
- **d.** seismic waves

2. Construct a portion of the Geological Time Scale similar to this one.

Using the "Geological Time Scale" on page 312, place the following events in their approximate places.

- **a.** Burgess Shale
- **b.** Cambrian Explosion
- **c.** first appearance of land plants in fossil record
- **d.** first appearance of animals with backbones in fossil record
- **e.** first appearance of land-dwelling animals
- **f.** microscopic marine organisms thrive—source of Alberta's future petroleum

Applying Concepts

3. The speed of a seismic wave depends mostly upon the density of material the wave is travelling through. In general, the denser the material, the faster the wave travels. The following table represents typical densities for crude oil—a common form of petroleum—and a few types of rock.

Material	crude oil	limestone	sandstone	shale
Density (g/cm^3)	0.9	2.5	2.3	2.2

When the seismic wave encounters a boundary between two layers of rock with different densities, the sudden change in speed can cause a reflection to occur. It is usually the case that the larger the speed difference between materials at the boundary, the stronger the reflection. The reflected part of the seismic wave is redirected toward the surface.

- **a.** If the seismic wave is capable of travelling through all of these materials, rank the materials from slowest to fastest.
- **b.** Which combination of materials would produce the strongest reflection?
- **c.** Which combination of materials would produce the weakest reflection?